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Selected thermal properties of cryo-ground coriander powder (var. RCR-41)

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Abstract

Thermal properties of cryo-ground coriander powder (var. RCR-41) such as specific heat, bulk thermal conductivity and bulk thermal diffusivity were investigated. It was observed that the specific heat increased from 347.63 to 3700.31 J $kg^{-1}K^{-1}$ with increase in temperature from -150 °C to 100°C and moisture content from 3.5% to 17.7% (db) and it showed a second order polynomial relationship with moisture content and temperature. The thermal conductivity increased non-linearly from 0.0884 to 0.1340 $Wm^{-1}K^{-1}$ with increase in moisture content from 3.5% to 17.7% (db) at 30°C. Thermal diffusivity varied non-linearly from 12.63×10^{-6} to 19.89×10^{-6} m^2s^{-1} with increase in moisture content from 3.5% to 17.7% (db) at 30°C. Both thermal conductivity and thermal diffusivity showed quadratic relationships with moisture content. The specific heat was affected significantly with moisture content and temperature ($P \leq 0.01$) and both thermal conductivity and thermal diffusivity were affected significantly by moisture content.

Keywords: coriander powder, specific heat, thermal conductivity, thermal diffusivity, thermal properties

Introduction

Coriander (*Coriandrum sativum*) is an annual herb in the family *Apiaceae* and native to southern Europe and North Africa and southwestern Asia. India is one of the largest producers of coriander which is used extensively in curry powder (Blade 1998). The seeds of coriander are almost ovate globular and there are many longitudinal ridges on its surface. The length of the seed is 3-5 mm and colour when dried is usually brown, but may also be green, straw-coloured or off white.

The most important constituents of coriander seeds are the essential oil and fatty oil. The essential oil content of dried coriander seeds varies between 0.03-2.60% and fatty oil content varies between 9.9-27.7%. Other constituents such as crude protein, fat, crude fibre and ash contents vary from 11.5-21.3%, 17.8-19.15%, 28.4-29.1% and 4.9-6.0%, respectively (Akgul 1993; Diederichsen 1996; Kaya *et al.* 2000; Ramadan & Morsel 2002).

In conventional method, coriander is converted into powder by the mechanical process of

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grinding and heat is generated in the grinder when energy is used to fracture a particle into a smaller size. This raises the temperature of the powder to as high as 95°C which ultimately leads to losses of essential oils, aroma and colour. The heat generation can be reduced by using cryogenic grinding technique and thus the quality of the powder can be retained (Singh & Goswami 2000; 2006). The knowledge of thermal properties *viz*., specific heat, thermal conductivity and thermal diffusivity are essential to design a cryogenic grinding system and simulate and model heat transfer phenomenon in the grinder (Singh & Goswami 2000; 2006).

The temperature and moisture content of agricultural materials greatly affect its thermal properties. Generally, specific heat is represented by a function of moisture content using linear relations (Mohsenin 1980). The method of mixtures has been the most common method for measurement of specific heat of agricultural materials (Mohsenin 1980). Though it is a direct technique it does not provide very accurate results. Using differential scanning calorimetry (DSC) technique, the specific heat of agricultural materials can be measured as a function of temperature. Various researchers have investigated the thermal properties using DSC for cumin seed (Singh & Goswami 2000), gram (Dutta *et al.* 1988), borage seeds (Yang *et al.* 2002) etc. A cylindrical device with a line heating source at the centre has also been used by various investigators to determine the thermal conductivity of a variety of materials based on transient heat transfer analysis (Chandra & Muir 1971; Singh & Goswami 2000).

The objective of this investigation was to determine the thermal properties of cryo-ground coriander powder, *viz*., specific heat, thermal conductivity and diffusivity and its variation with temperature and moisture content. The effect on specific heat with respect to moisture content and temperature and that of thermal conductivity and diffusivity with respect to moisture content at constant temperature of 30°C were investigated.

Materials and methods

Coriander (var. RCR-41) was procured from National Research Centre on Seed Spices, Tabiji, Ajmer, Rajasthan (India). The seeds were cleaned manually and broken, any foreign matter, split, deformed and immature seeds were removed from the sample before the experiment. The initial moisture content of seed was determined by the vacuum oven method at a temperature of 70°C and pressure of 100 mm Hg until a constant weight was obtained (Ranganna 1986). The initial moisture content of coriander was 7.0% (d.b.). Initially the seeds were stored at room temperature (25°C) for 2 to 3 weeks. To achieve the desired low moisture content, a predetermined quantity of coriander was dried in tray dryer at 55°C. To achieve high moisture content, a predetermined quantity of distilled water was added and mixed thoroughly to ensure uniform moisture distribution. The samples were packed in sealed moisture resistant flexible pouches and kept at 5°C in refrigerator for 48 h so that uniform distribution of moisture throughout the seed takes place. For measurement of thermal properties, the pouches were taken out from the refrigerator and allowed to warm up to room temperature for 2 to 3 h. Five levels of moisture content, *viz*., 3.5%, 7.1%, 9.8%, 14.8% and 17.7% db were used in this study. The experiments were carried out at Thermal and Physical Properties Laboratory of Indian Institute of Technology (IIT), Kharagpur, India. The conditioned coriander samples were ground in a grinder (Model Pulverisette 14, Fritsch Industries, Germany) using liquid nitrogen (L N_2) to ensure that properties of coriander powder do not vary significantly and thus cryo- ground coriander samples were used for determination of thermal properties.

The specific heat of the cryo-ground coriander samples was determined by Differential Scanning Calorimetry (Netzsch DSC 204 'Phoenix', Germany). Before conducting the experiments, the calibration of DSC was carried out for range from -150°C to 350°C. For determination of specific heat, the cryo-ground coriander samples were kept in an aluminium crucible in small quantity (between 8.200 to

11.200 mg) at all five moisture levels. The aluminium crucible was closed and run in the DSC for the temperature range from -150°C to 350°C. Under this experiment, thermograms were obtained and the variation of specific heat with temperature were determined by the method reported by Singh & Goswami (2000; 2006) for each moisture content. Considering that most of the spice grinding (cryogenic as well as conventional) takes place between -150°C to 100°C, the data was taken between this range for the present investigation.

For determination of bulk thermal conductivity of the cryo-ground coriander samples, a quick thermal conductivity meter (Model: Kemtherm QTM-D3, Kyoto Electronics Manufacturing Co. Ltd, Tokyo, Japan) was used. The thermal conductivity meter was calibrated using standard reference plate. After calibration, a sample pan of volume 100 cm^3 was filled with cryo-ground coriander samples for determination of thermal conductivity. The weight of coriander sample in pan of volume 100 cm^3 was also measured to calculate the bulk density of the samples. The experiments were conducted in triplicate for all five moisture levels at average sample temperature of 30°C in the thermal conductivity meter and the mean values are reported in the study.

The bulk thermal diffusivity of cryo-ground coriander samples was calculated by using experimentally obtained values of specific heat, bulk thermal conductivity and bulk density by using Eq.(1) at 30°C (Singh & Goswami 2000):

$$\alpha_b = k_b / \rho_b C_p \tag{1}$$

where α_b is the bulk thermal diffusivity ($m^2\ s^{-1}$); k_b the bulk thermal conductivity ($W\ m^{-1}\ K^{-1}$); C_p the specific heat ($J\ kg^{-1}\ K^{-1}$) and ρ_b the bulk density ($kg\ m^{-3}$).

Statistica 6.0 and Microsoft Excel 2003 softwares were used to analyse the data for obtaining the variation of specific heat with temperature and moisture content. Analysis of variance (ANOVA) test was also performed for analysis of the thermal properties and presented in Table 1.

Results and discussion

Specific heat

The specific heat of coriander sample increased with moisture content (Fig. 2). Similar trend was reported in cumin seed (Singh & Goswami 2000), sheanut kernel (Aviara & Haque 2001) and borage seed (Yang *et al*. 2002) etc. From Table 1, it was also inferred that the specific heat of coriander sample was affected significantly ($P<0.01$) by moisture content and temperature. The specific heat increased from 347.63 to 3700.31 $J\ kg^{-1}\ K^{-1}$ with increase in moisture content from 3.5% to 17.7% (db) and temperature from -150°C to 100°C (Figs. 1 & 2). The relationships of specific heat with temperature and moisture content are presented in Tables 2 & 3. These will be helpful in predicting the specific heat at different moisture content and temperature levels.

Table 1. ANOVA for specific heat, thermal conductivity and thermal diffusivity of cryo-ground coriander powder

Source	d.f.	Mean Square	F-value	P-value
Specific heat				
Moisture content	1	36279701	58.3*	2.49E-10
Temperature	1	37957661	60.7*	1.39E-10
Thermal conductivity				
Moisture content	1	272.95	16.6*	0.003555
Thermal diffusivity				
Moisture content	1	278.68	16.9*	0.003352

*Significant at P< 0.01; F tabulated values at the degree of freedom 1, 58 is 7.09 and 1, 46 is 7.22

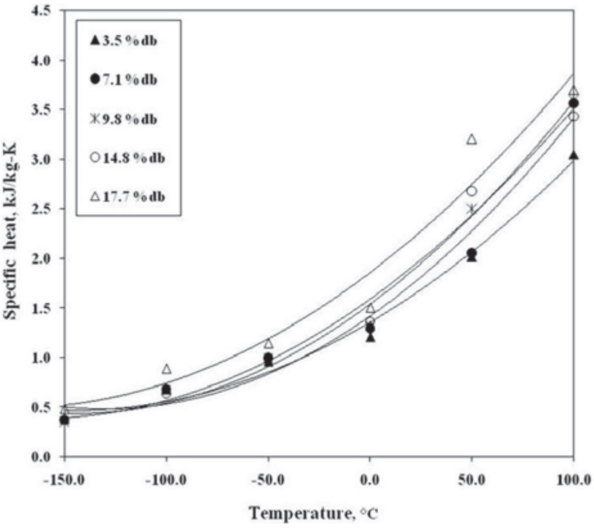

Fig. 1. Influence of temperature on specific heat of cryo-ground coriander powder (var.RCR-41)

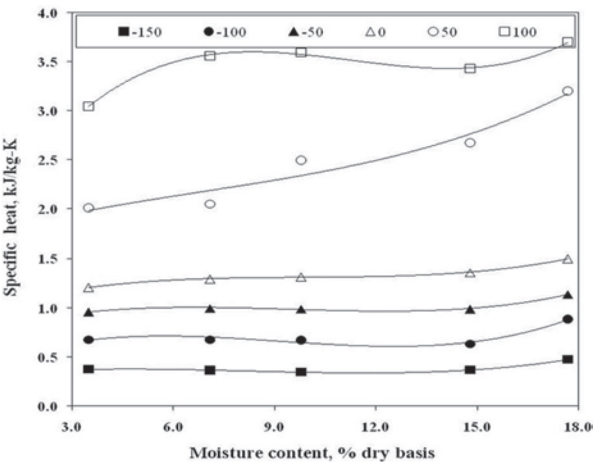

Fig. 2. Influence of moisture content on specific heat of cryo-ground coriander powder (var. RCR-41)

Thermal conductivity

Fig. 3 shows the bulk thermal conductivity of coriander sample at an average temperature of 30°C. From the figure, it is clear that the bulk

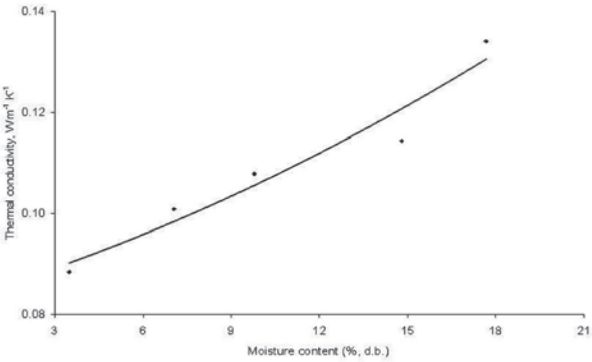

Fig. 3. Variation of thermal conductivity of coriander sample on moisture content at 30°C

thermal conductivity increased with increase in moisture content. Various researchers have also reported similar trend for the thermal conductivity of cumin seed (Singh & Goswami 2000), sheanut kernel (Aviara & Haque 2001) and borage seed (Yang *et al*. 2002). It was found that the thermal conductivity of coriander samples increased from 0.0884 to 0.1340 $Wm^{-1} K^{-1}$ with increase in moisture content from 3.5% to 17.7% (db) at an average temperature of 30°C. The relationship between thermal conductivity and moisture content can be expressed by Equation (3):

$$k_b = 5x10^{-5} M^2 + 0.0017M + 0.0835 \quad (r^2 = 0.94) \quad (3)$$

for 3.5% (*db*) ≤ M ≤17.7% (*db*)

Some researchers also reported similar results, e.g. Chandra & Muir (1971) for wheat and Singh & Goswami (2000) for cumin. From Table 1, it was seen that thermal conductivity was affected significantly by moisture content at 1% level of significance.

Thermal diffusivity

Using Equation (1), the thermal diffusivity of coriander samples at 30°C was calculated and

Table 2. Second order regression equations for specific heat of coriander sample with respect to moisture content and temperature

Moisture content (% d.b.)	Second order regression equation	R^2
3.5	$C_p = 4E\text{-}05T^2 + 0.012T + 1.354$	0.987
7.1	$C_p = 6E\text{-}05T^2 + 0.014T + 1.411$	0.977
9.8	$C_p = 5E\text{-}05T^2 + 0.015T + 1.535$	0.988
14.8	$C_p = 4E\text{-}05T^2 + 0.014T + 1.587$	0.983
17.7	$C_p = 4E\text{-}05T^2 + 0.015T + 1.853$	0.955

Table 3. Third order regression equations for specific heat of coriander sample with respect to temperature and moisture content

Temperature (°C)	Third order regression equation	R^2
-150	$C_p = 0.000M^3 - 0.005M^2 + 0.038M + 0.300$	0.999
-100	$C_p = 0.000M^3 - 0.018M^2 + 0.144M + 0.358$	0.954
-50	$C_p = 0.000M^3 - 0.012M^2 + 0.104M + 0.718$	0.991
0	$C_p = 0.000M^3 - 0.010M^2 + 0.105M + 0.948$	0.998
50	$C_p = 0.000M^3 - 0.007M^2 + 0.101M + 1.696$	0.945
100	$C_p = 0.001M^3 - 0.058M^2 + 0.616M + 1.529$	0.997

its variation with moisture content is represented in Fig. 4. It is inferred from the figure that thermal diffusivity varied non-linearly from 12.63×10^{-6} to 19.89×10^{-6} m^2s^{-1} with increasing moisture content from 3.5% to 17.7% (db) at 30°C. The relationship between thermal diffusivity (α_b) and moisture content (M) has been reported to be both ascending [e.g. for gram (Dutta *et al.* 1988)] and descending [e.g. for borage seeds (Yang *et al.* 2002) and for cumin seed (Singh & Goswami 2000)]. It is clear from equation (1) that the magnitude of thermal diffusivity (α_b) depended on the combined effect of k_b, p_b and C_p. When value of k_b increases faster than that of p_b and C_p in the same temperature and moisture ranges for the material, thermal diffusivity would increase with increase in moisture content e.g. for gram (Dutta *et al.* 1988, Yang *et al*. 2002). The relationship between thermal diffusivity with moisture content can be represented by Equation (4):

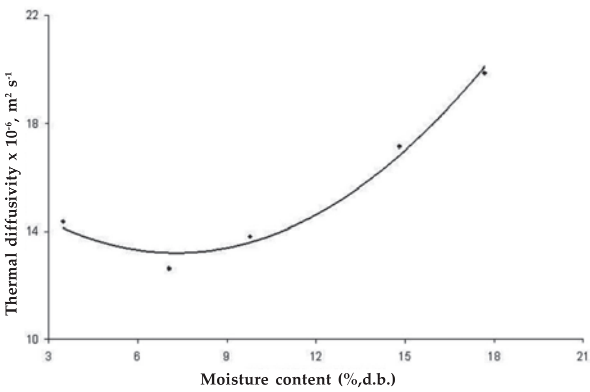

Fig. 4. Variation of thermal diffusivity of cryo-ground coriander sample on moisture content at 30°C

$$\alpha_b = 0.0642M^2 - 0.9358M + 16.61 \quad (r^2 = 0.98) \quad (4)$$

for 3.5% (*db*) ≤ M ≤17.7% (*db*)

It was observed that thermal diffusivity was affected significantly by moisture content at 1% level of significance (Table 1).

From the present investigation, it was observed that the specific heat cryo-ground coriander powder increased from 347.63 to 3700.31 J kg^{-1} K^{-1} with increase in moisture content from 3.5% to 17.7% (db) and temperature from -150°C to 100°C. The variation showed a second order polynomial with moisture content and temperature. It was affected significantly ($P\leq0.01$) by moisture content and temperature. Thermal conductivity of coriander increased from 0.0884 to 0.1340 W m^{-1} K^{-1} with increase in moisture content from 3.5% to 17.7% (db) at 30°C. The variation showed a second order relationship with moisture content and it was affected significantly by moisture content. Thermal diffusivity of coriander varied from 12.63×10^{-6} to 19.89×10^{-6} m^2 s^{-1} at 30°C with increase of moisture content from 3.5% to 17.7% (db). It was affected significantly by moisture content and the variation showed a quadratic relationship with moisture content.

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